

We claim:

1. A light emitting device, comprising:  
a radiation source;  
a luminescent material; and  
5 a radiation scattering material located between the radiation source and the luminescent material.

2. The device of claim 1, wherein:  
the radiation source comprises a light emitting diode or a laser diode  
10 emitting radiation having a first peak wavelength; and  
the luminescent material comprises a phosphor which emits radiation having a second peak wavelength in response to incident radiation source radiation.

3. The device of claim 2, wherein:  
the radiation source comprises a blue or ultraviolet light emitting diode or laser diode; and  
the luminescent material comprises a phosphor layer or a dispersion of a phosphor and a transmissive encapsulating material.

4. The device of claim 2, wherein:  
the radiation source comprises a blue light emitting diode; and  
the luminescent material comprises a yellow light emitting phosphor layer or a dispersion of a yellow light emitting phosphor in a polymer material.

5. The device of claim 4, wherein the light emitting diode comprises a blue emitting InGaN light emitting diode and the luminescent material comprises a dispersion of an epoxy or silicone and a YAG:Ce<sup>3+</sup> phosphor.

6. The device of claim 3, wherein the radiation source comprises an ultraviolet light emitting diode and the luminescent material emits white light in response to the ultraviolet radiation emitted by the light emitting diode.

7. The device of claim 2, wherein the luminescent material comprises an organic dye.

8. The device of claim 2, wherein the radiation scattering material comprises a layer of packed radiation scattering particles.

9. The device of claim 2, wherein the radiation scattering material comprises radiation scattering particles in a carrier medium comprising a transmissive body.

10. The device of claim 9, wherein:  
the radiation scattering particles comprise particles selected from a group consisting of  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$ ; and  
the carrier medium is selected from glass, silicone and plastic material.

11. The device of claim 9, wherein:  
the radiation scattering particles comprise 140 to 240 nm particles selected from a group consisting of  $\text{TiO}_2$ ,  $\text{BaTiO}_3$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{CaCO}_3$ ,  $\text{BaSO}_4$ , and diamond; and  
the carrier medium is selected from glass, epoxy, silicone and urea resin.

12. The device of claim 9, further comprising:  
a package supporting the radiation source comprising a light emitting diode; and

wherein the radiation scattering particles in the carrier medium are located above the light emitting diode and the luminescent material is located above the radiation scattering particles in the carrier medium.

5 13. The device of claim 12, wherein the radiation scattering particles in a carrier medium comprise at least one of the following:

a) at least one light or UV radiation scattering particle layer in a glass passivation layer directly over the light emitting diode; and

10 b) light or UV radiation scattering particles in a silicone layer over the light emitting diode or over and on sides of the light emitting diode.

14. The device of claim 13, further comprising:

c) a light or UV radiation scattering layer on sidewalls of a reflector cup portion of the package containing the light emitting diode.

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15. The device of claim 14, wherein the radiation scattering material comprises all three of a), b) and c).

16. The device of claim 9, wherein the radiation scattering particles in a carrier medium comprise at least two layers of  $\text{TiO}_2$  particles in about a 1 micron to about a 2 micron thick silica layer arranged to achieve photonic crystal effects.

17. The device of claim 9, wherein a mean diameter of the radiation scattering particles is between  $\lambda/3$  and  $\lambda/2$ , where  $\lambda$  is the peak emission wavelength of the radiation source.

18. The device of claim 17, wherein the radiation scattering particles scatter at least 50% more radiation source radiation than luminescent material radiation.

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19. The device of claim 1, wherein the radiation scattering material does not luminesce and the luminescent material does not substantially scatter light or UV radiation.

5 20. The device of claim 19, wherein the luminescent material comprises a nanocrystalline phosphor or an organic dye.

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21. A white light emitting device, comprising:  
a package containing a reflector cup;  
a light emitting diode in the reflector cup;  
radiation scattering particles in a packed layer or in a carrier medium  
over the light emitting diode; and  
a phosphor or an organic dye which emits radiation having a second peak  
wavelength in response to incident light emitting diode radiation having a first  
15 peak wavelength, such that the device output appears white to an observer.

22. The device of claim 21, wherein:  
the light emitting diode comprises a blue or an ultraviolet light emitting diode;  
20 the radiation scattering particles comprise light or UV radiation scattering particles in a carrier medium; and  
the luminescent material comprises a yellow or white light emitting phosphor layer or a dispersion of a phosphor in an epoxy or silicone.

25 23. The device of claim 22, wherein:  
the light emitting diode comprises a light emitting diode having an emission wavelength of 365 to 420 nm; and  
the luminescent material comprises:  
i) a white light emitting phosphor layer comprising one or  
30 more phosphors; or

- ii) a dispersion of at least one phosphor and an epoxy or silicone.

24. The device of claim 22, wherein the light emitting diode comprises a blue emitting InGaN light emitting diode and the luminescent material comprises a dispersion of an epoxy or silicone and a YAG:Ce<sup>3+</sup> phosphor.

25. The device of claim 22, wherein:  
the radiation scattering particles are selected from a group consisting of TiO<sub>2</sub>, BaTiO<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, CaCO<sub>3</sub>, BaSO<sub>4</sub> and diamond particles having a mean diameter of 50 to 500 nm; and  
the carrier medium is selected from glass, epoxy, silicone and urea resin.

26. The device of claim 25, wherein the light scattering particles in a carrier medium comprise at least one of the following:  
a) light or UV radiation scattering particles in a glass passivation layer over the light emitting diode; and  
b) light or UV radiation scattering particles in a silicone layer over the light emitting diode or over and on sides of the light emitting diode.

27. The device of claim 26, wherein the light scattering particles in a carrier medium comprise both a), b) and  
c) a light or UV radiation scattering layer on sidewalls of the reflector cup.

28. The device of claim 27, wherein the particles in the glass passivation layer comprise 120 to 200 nm TiO<sub>2</sub> particles in a silica glass layer.

29. The device of claim 27, wherein the particles in the silicone layer comprise a silicone layer containing 5-10% of 120 to 200 nm amorphous silica particles in contact with the top and the sides of the light emitting diode.

5 30. The device of claim 27, wherein the light or UV radiation scattering layer on the sidewalls of the reflector cup comprises a  $\text{MgF}_2$  layer or a polymer layer.

31. The device of claim 22, wherein:

10 a mean diameter of the radiation scattering particles is between  $\lambda/3$  and  $\lambda/2$ , where  $\lambda$  is the peak emission wavelength of the radiation source; and  
the radiation scattering particles scatter at least 50% more radiation source radiation than luminescent material radiation.

15 32. A method of generating white light comprising:  
supplying power to a light emitting diode;  
generating a directional blue light or ultraviolet radiation;  
passing the blue light or ultraviolet radiation through a light or radiation  
scattering material to diffuse the blue light or ultraviolet radiation in a plurality  
20 of directions;  
providing the diffuse blue light or ultraviolet radiation onto a luminescent material; and  
generating white light.

25 33. The method of claim 32, wherein:  
the first step of generating comprises generating blue light;  
the step of passing comprises passing the blue light through light scattering particles;  
the step of providing comprises providing the diffuse blue light onto a  
30 yellow light emitting phosphor; and

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the second step of generating comprises providing a mix of the yellow light from the phosphor and the blue light from the light emitting diode that is transmitted through the phosphor.

5     34.     The method of claim 32, wherein:

the first step of generating comprises generating radiation having a wavelength between 365 and 420 nm;

the step of passing comprises passing the radiation through radiation scattering particles;

10     the step of providing comprises providing the diffuse radiation onto at least one white light emitting phosphor; and

the second step of generating comprises generating white light from the at least one phosphor.

15     35.     The method of claim 34, wherein the radiation comprises ultraviolet radiation.

36.     A light emitting device, comprising:

a radiation source;

20     a luminescent material layer which does not substantially exhibit Mie scattering; and

a radiation scattering phosphor layer, which exhibits Mie scattering of the radiation source radiation, located between the radiation source and the luminescent material.

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37.     The device of claim 36, wherein:

the radiation source comprises a blue light emitting diode;

the luminescent material layer comprises a discrete yellow light emitting phosphor layer having first a mean particle diameter; and

the radiation scattering phosphor layer comprises a discrete yellow emitting phosphor layer having a second mean particle diameter smaller than the first mean particle diameter.

- 5 38. The device of claim 37, wherein the luminescent material comprises YAG:Ce<sup>3+</sup> having a mean particle diameter between 1 to 10 microns and the radiation scattering phosphor comprises YAG:Ce<sup>3+</sup> having a mean particle diameter between 120 and 200 nm.

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